Administrivia

- Project 2b (parts 4, 5, 6) due tomorrow at 11:59 pm
  - Questions?
- Project 3 Light to be released tomorrow
- Project 3 Full will be same as Autumn 2008
  - http://www.cs.washington.edu/education/courses/451/08au/projects/project3/
- Feedback for Steve, Ryan, Sean?
- Rest of the time: Some slides taken from previous quarter for full version of Project 3
  - Probably still useful for Project 3 Light

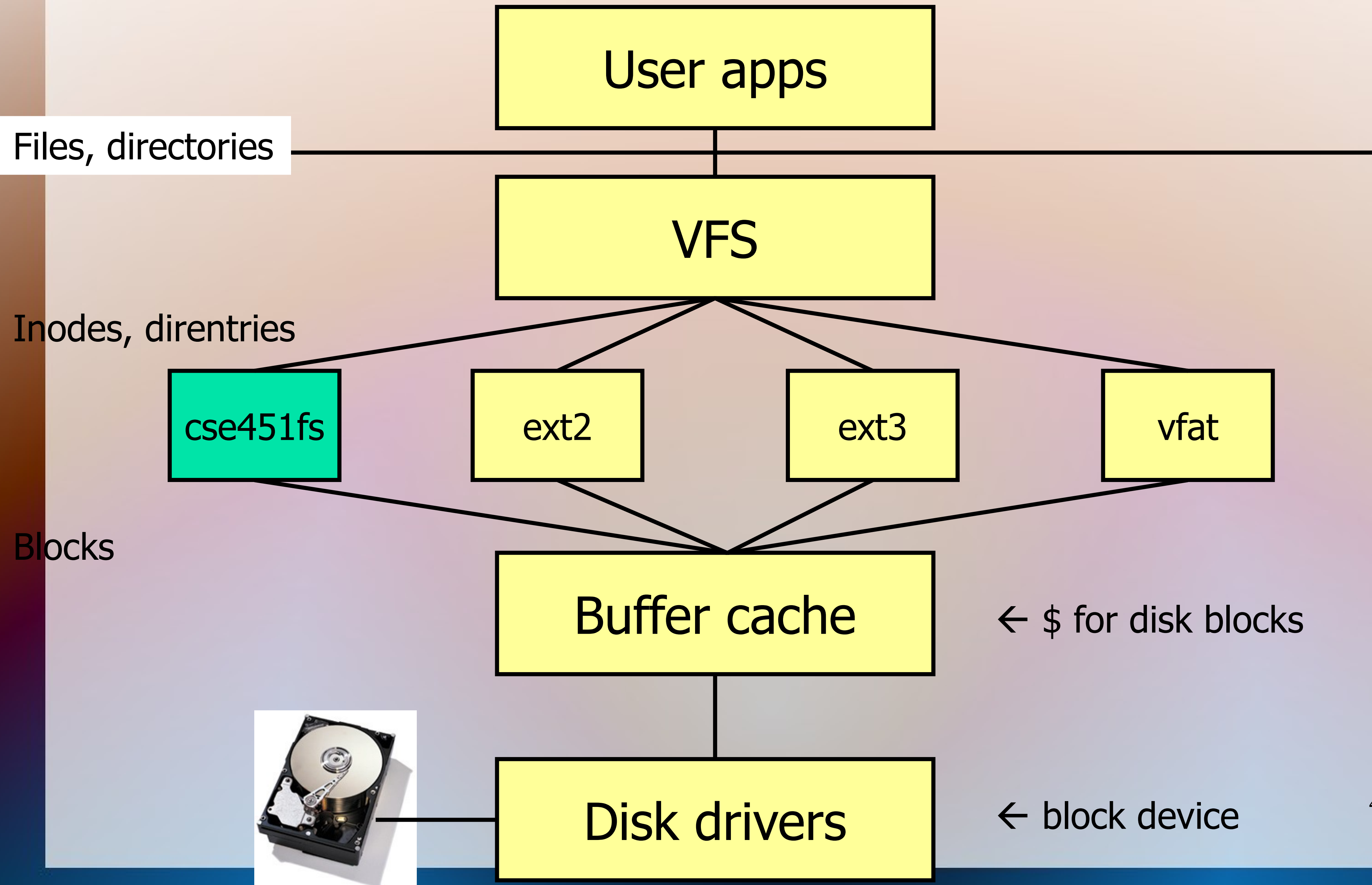
Project 3

- Work with a real file system
- Given:
  - cse451fs: simplified file system for Linux
- Goals:
  - Understand how it works
  - Modify implementation to:
    - Increase maximum size of files (currently 13KB)
    - Allow for longer file names (currently 30 chars)

Project 3 Setup

- Build a kernel module for cse451fs
- Transfer it to VMware
- On VMware
  - load the cse451fs module
  - format the file system using (modified) mkfs tool
  - mount your file system
  - Test using tools like ls, cat, etc. (see last slides for gotchas)
- Step 1: try this procedure with given code
- Step 2: read cse451fs.h, then dir.c

Linux FS layers



File systems in Linux

- Organize blocks in a block device into files and directories

Core concepts:

- Inodes and inode numbers
  - Inode = structure maintaining all metadata about a file, except for name
    - So, where are file names stored?
  - Inode number = unique ID of inode
  - One or more file *names* can point (link) to the same inode
  - Inode numbers provide location independence
- Directory entry
  - A pair (name, inode number)
  - A directory is *just a file*, whose contents is a list of directory entries
  - Directories have a bit set to tell user/shell/OS to treat file as a directory

File system disk structure

- What types of things do we need to store in a file system?

cse451fs disk structure

boot	superblock	data map	inode blocks	data blocks

- **Superblock**: tells where all other things are
  - Contains **inode map**:
    - Bit array, tracks which inodes are currently in use
  - Contains parameter values (e.g., block size)
- **Data map**:
  - Bit array, tracks which data blocks are in use
- **Inode blocks**:
  - Contains all inodes (i.e., metadata for files) stored here
- **Data blocks**:
  - Contains data of files / directories

cse451fs structure

1	1	1	85	4008
boot	superblock	data map	inode blocks	data blocks

```
        struct cse451_super_block {
1365       __u16 s_nNumInodes;               // inode map is tail of superblock
2          __u16 s_nDataMapStart;            // block # of first data map block
1          __u32 s_nDataMapBlocks;           // data map size, in blocks
3          __u32 s_nInodeStart;              // block # of first inode block
85         __u32 s_nNumInodeBlocks;          // number of blocks of inodes
88         __u32 s_nDataBlocksStart;         // block # of first data block
4008       __u32 s_nDataBlocks;              // number of blocks of data
7          __u32 s_nBusyInodes;              // number of inodes in use
0x451f     __u16 s_magic;                    // magic number
           unsigned long s_imap;                     // name for inode map
        };
```

Sample values for a 4MB disk with 4 files and 3 dirs using 1K blocks

Inode structure

```
#define CSE451_NUMDATAPTRS 10

struct cse451_inode {
   __u16 i_mode;          ← determines if file or dir
   __u16 i_nlinks;          (+ protection)
   __u16 i_uid;
   __u16 i_gid;
   __u32 i_filesize;
   __u32 i_datablocks[CSE451_NUMDATAPTRS];
};
```

Inode structure

```
#define CSE451_NUMDATAPTRS 10

struct cse451_inode {
   __u16 i_mode;            ← determines if file or dir
   __u16 i_nlinks;            (+ protection)
   __u16 i_uid;
   __u16 i_gid;
   __u32 i_filesize;
   __u32 i_datablocks[CSE451_NUMDATAPTRS];
};
```

- What's the size of the inode struct?
- Multiple inodes per block
  - How many for 1K block?
- mkfs decides how many inodes to create, using heuristic
  - create an inode for every three data blocks
- In general, the max number of inodes (so of files) is decided at FS formatting time

Data blocks

- Blocks for regular files contain file data
- Blocks for directories contain directory entries:

```
#define CSE451_MAXDIRNAMELENGTH   30

struct cse451_dir_entry {
  __u16 inode;
  char name[CSE451_MAXDIRNAMELENGTH];
};
```

- Data block for / directory containing:
  .   ..   etc   bin

Data block for /

Dir. entry	Field	Value
0	Inode	1
	Name	"."
1	Inode	1
	Name	".."
2	Inode	2
	Name	"etc"
3	Inode	3
	Name	"bin"
4	Inode	0
	Name	0

Sample data block usage

For a 4MB file system with 1KB blocks

- /
  - etc
    - passwd
    - fstab
  - bin
    - sh
    - date

File/Directory	Size	Data Blocks
/	4 entries + 1 null entry	1
/etc	4 entries + 1 null entry	1
/bin	4 entries + 1 null entry	1
/etc/passwd	1024 bytes	1
/etc/fstab	100 bytes	1
/bin/sh	10,000 bytes	10
/bin/date	5,000 bytes	5
	Total:	**20**

Project 3 requirements

- Increase maximum sizes of files
  - Be efficient for small files but allow large files
  - Changing constant (=10) is **not enough**!
  - Come up with a better design/structure for locating data blocks
    - E.g., indirect blocks?
  - You don't have to support arbitrarily large files
    - Fine to have constant new_max (but new_max >> old_max)

- Allow for longer file names
  - Be efficient for short files names but allow large file names
  - Again, *don't just change the constant*

Approaches for longer file names

- Store long names in a separate data block, and keep a pointer to that in the directory entry.
  - Short names can be stored as they are.
  - Recommended
- Combine multiple fixed-length dir entries into a single long dir entry (win95)
  - It is easier if the entries are adjacent.
- Put a length field in the dir entry and store variable length strings
  - need to make sure that when reading a directory, that you are positioned at the beginning of an entry.

Getting started with the code

- Understand the source of the limits in the existing implementation
  - Look at the code that manipulates dir entries
    - mkfs code
    - dir.c in the file system source code
- Longer file names:
  - The code for will largely be in dir.c: add_entry() and find_entry()
  - In mkfs, change how the first two entries (for "." and "..") are stored
- Bigger files:
  - super.c:get_block()
  - References to i_datablock[] array in an inode will have to change

Linux Buffer Manager Code

- To manipulate disk blocks, you need to go through the buffer cache
- Linux buffer cache fundamentals:
  - blocks are represented by buffer_heads
    - Just another data structure
  - Actual data is in buffer_head->b_data
  - For a given disk block, buffer manager could be:
    - Completely unaware of it
      - no buffer_head exists, block not in memory
    - Aware of block information
      - buffer_head exists, but block data (b_data) not in memory
    - Aware of block information and data
      - Both the buffer_head and its b_data are valid ("$ hit")

Accessing blocks

- To read a block, FS uses bread(…):
  - Find the corresponding buffer_head
    - Create if doesn’t exist
  - Make sure the data is in memory (read from disk if necessary)

- To write a block:
  - mark_buffer_dirty() + brelse() - mark buffer as changed and release to kernel (which does the writing)

Tool limitation warning

- Some stuff in linux kernel is limited to 256 chars
  - e.g. VFS, ls
  - Be careful when testing long filenames!
- `dd` is useful for creating large test files
  - dd if=/dev/zero of=200k bs=1024 count=200
- `df` is useful to check you're freeing everything correctly

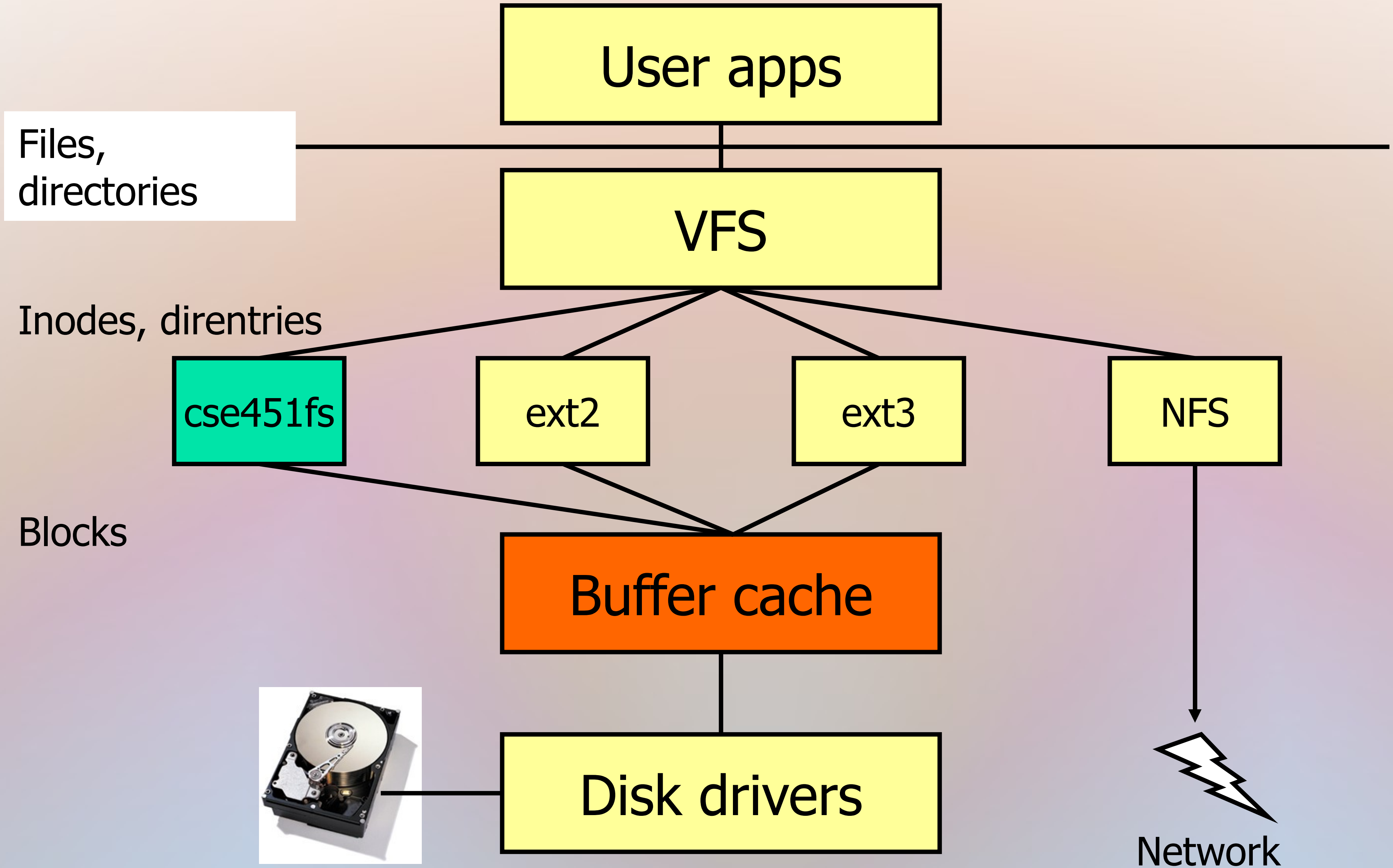
Gcc warning

- gcc might insert extra space into structs
  - How big do you think this is?
    `struct test { char a; int b; }`
  - Why is this a problem?
    - What if `test` represents something you want on disk?
      - e.g. directory entries
    - Discrepancy between the disk layout and memory layout
  - Fix:

```
struct test2 {
      char a;
      int b;
} __attribute__((packed));
```

- `sizeof(test2)` is now 5

Linux FS Layers (Revisit)



Linux Buffer Manager

- Buffer cache caches disk blocks & buffers writes
  - When you write to a file, the data goes into buffer cache (for write-back buffer caches)
  - Sync is required to flush the data to disk
    - Update and bdflush processes flush data to disk (every 30s)
- Linux buffer cache code fundamentals:
  - Blocks are represented by *buffer_heads*
    - Actual data is in *buffer_head->b_data*
  - For a given disk block, buffer manager could be:
    - Completely unaware of it
      - no *buffer_head* exists, block not in memory
    - Aware of block information
      - *buffer_head* exists, but block data (*b_data*) not in memory
    - Aware of block information and data
      - Both the *buffer_head* and its *b_data* are valid ("$ hit")

Accessing blocks

- To read a block, FS uses sb_bread(…):
  - Find the corresponding *buffer_head*
    - Create if doesn't exist
  - Make sure *buffer_head->b_data* is in memory (read from disk if necessary)

- To write a block:
  - mark_buffer_dirty() + brelse() - mark buffer as changed and release to kernel (which does the writing)

Some buffer manager functions

cse451_bread(pbh, inode, block, create)	Get the *buffer_head* for the given disk block, ensuring that the data is in memory and ready for use. Increments ref count; always pair with a brelse.
cse451_getblk(pbh, inode, block, create)	Get the *buffer_head* for the given disk block. Does not guarantee anything about the state of the actual data. Increments ref count; always pair with a brelse. Zeros out new blocks (required for security).
brelse(bh)	Decrement the ref. count of the given buffer.
mark_buffer_dirty(bh)	Mark the buffer modified, meaning needs to be written to disk at some point.
mark_buffer_uptodate(bh)	Indicate that the data pointed to by bh is valid.

[Remember this lock-release pattern for future use in multi-threaded (multi-process) programs; it's how reference-counted pointers also work.]

Network File Systems

- Provide access to remote files over a network
  - Typically aim for location and network transparency
- Designed and optimized for different types of operations
  - E.g., work over LANs, over WANs, support disconnected operations, fault-tolerance, scalability, consistency, etc.

Examples:

- Network File System (NFS) – Sun Microsystems
- Server Message Block (SMB) – originally IBM, Microsoft
- Andrew File System (AFS) – CMU
- Coda – CMU

NFS

- A server exports (or shares) a directory
- A client mounts the remote directory onto his local FS namespace
  - The mounted directory looks like an integral subtree of the local file system, replacing the subtree descending from the local directory [1]
  - However, it's all namespace magic, nothing is actually stored on local disks

[1] *http://www.csie.fju.edu.tw/~yeh/courses/spring08/os/ch11.ppt*

Mounting an NFS Export

- A remote exported directory can be "glued" onto the local hierarchy

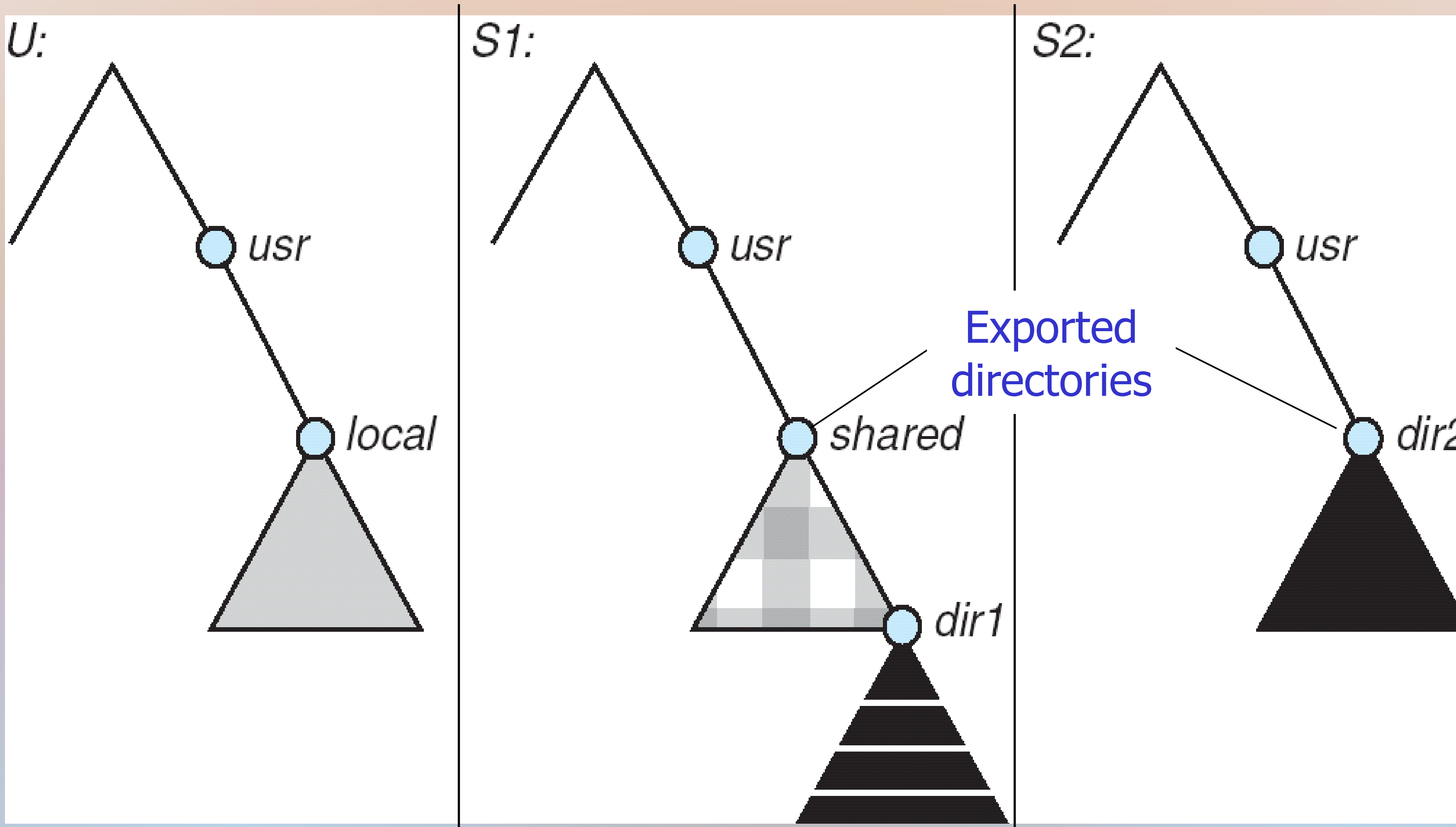


Figure taken from *http://www.csie.fju.edu.tw/~yeh/courses/spring08/os/ch11.ppt*

The NFS Protocol

- NFS is designed to operate in a heterogeneous environment of different machines, operating systems, and network architectures
  - NFS specifications are independent of these media
- This independence is achieved through the use of RPC and XDR (eXternal Data Representation)
- Nearly one-to-one correspondence between regular UNIX file system calls and the NFS protocol RPCs
  - looking up a file within a directory
  - reading a set of directory entries
  - accessing file attributes
  - reading and writing files

Bullets taken from presentation at *http://www.csie.fju.edu.tw/~yeh/courses/spring08/os/ch11.ppt*

The NFS Architecture

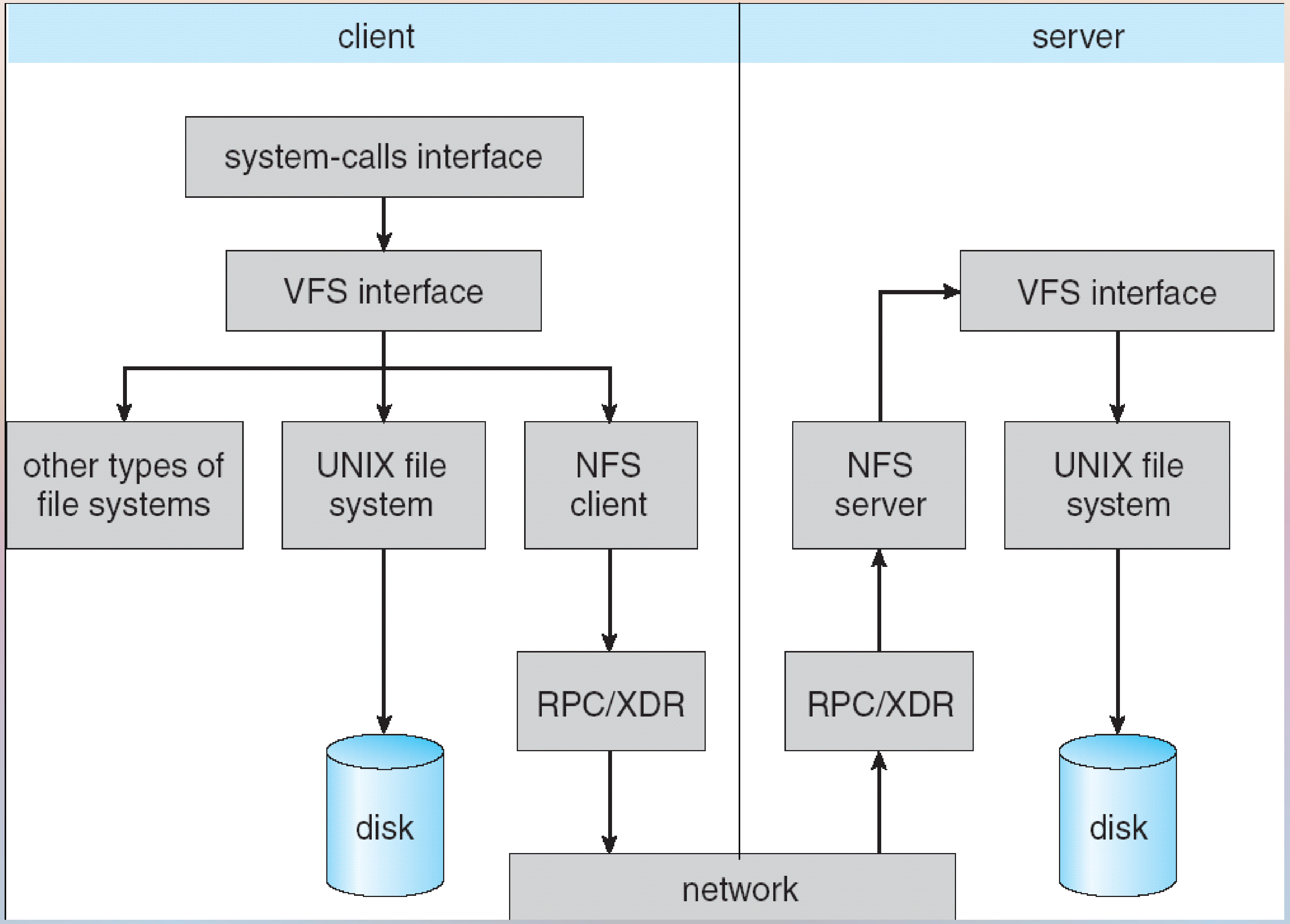


Figure taken from *http://www.csie.fju.edu.tw/~yeh/courses/spring08/os/ch11.ppt*

Example: Setting up an NFS Share

- Server exports directory
  - Check nfsd is running and it if not (e.g., service nfsd start)
  - Edit /etc/exports file
    - `/usr/shared  192.168.0.0/255.255.255.0(rw)`
    - `man exports` for more detailed structure of file
  - Force nfsd to re-read /etc/exports using `exportfs -ra`

- Client mounts the remote directory locally
  - `mount -t nfs 192.168.0.1:/usr/share /usr/local`

    (192.168.0.1 is the server's IP address)
  - can enable automatic mounting by editing `/etc/fstab` (`man fstab`)

Note:

- The above is just a "by-hand" example; use the Internet for more precise tutorials and troubleshooting